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Effect of Duration of Play on Injury Rate in Men's and Women's NCAA Sport

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By

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ABSTRACT

Injury rates increase with added athletic exposures. Mental and physical fatigue is potentially a component of this increase. However, large scale exposure-related injury trends by injury type, sport and sex are scarce. Consequently, the aim of this thesis was to determine whether injury rates are higher later in games and whether these rates vary with respect to sport, injury type and sex. NCAA injury data collected by the Datalys Center for Sports Injury Research and Prevention indicate that relative injury frequency increases in subsequent periods and this increase is uniform across sports. Subsequent period relative injury frequencies were greater in women and concussions and spasms showed the greatest subsequent period and sex (women greater than men) bias. This thesis is the first large scale report to show that injury rate increases with prolonged exposure and warrants further investigation into the relationship between other components of fatigue and specific injuries like concussion.

DEDICATION

This thesis is dedicated to my family, friends and teachers who have all supported me in different ways over the years.

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ABBREVIATIONS

Ach - Acetylcholine

ACSM - American College of Sports Medicine

CNS - Central Nervous System

CSF - Cerebrospinal Fluid

FITT - Frequency Intensity Time Type

ISS - Injury Surveillance System

K^+- Potassium

Min - Minutes

MLB - Major League Baseball

Na^+ - Sodium

NCAA - National Collegiate Athletics Association

NFL - National Football League

NHL - National Hockey League

SD - Standard Deviation

PROLOGUE

The 2013-2014 National Hockey League season culminated in a matchup between the Los Angeles Kings and the New York Rangers in the Stanley Cup final. Prior to the series, both teams were praised for their depth of talent at the centre-ice position. Depth at centre, or any other position, allows for a team's coach to distribute ice time at this position more evenly than coaches of other teams. In fact, the difference in average ice-time between the top line centre and the fourth line centre (the last on the depth chart) was a mere six minutes per game for both teams in the regular season and in the playoffs (NHL.com). Alternatively, teams who could not boast the same depth at centre had differences of as many as eight to ten minutes between their top and bottom line centres and did not qualify for the playoffs (NHL.com). Intuitively, the more evenly playing time is distributed, the less fatigued the players at the top of the ice-time hierarchy should be. As such, depth provides an obvious advantage for a team's success in that it allows first-line players to be more 'fresh' when they are needed to take control of a game. A potential, and perhaps not so obvious advantage, is that 'deeper' teams may not be as susceptible to injury.

During the same 2013-2014 NHL season, 29 centres played a minimum of 19 minutes of ice-time per game [See Table (Prologue)]. Over the course of the season, those players played nearly two fewer games each (73.3), than the centres who played between 16:00 and 18:59 minutes per game (75.1). This is somewhat unique to the 2013-2014 season. Over the last five full NHL seasons, centres averaging greater than 19 minutes per game have played 74.8 games per season, whereas those playing 16-19 minutes played 73.9 games per year. However, when examining the types of players in each of these two ice-time factions, one might expect that the players who play more in a game would be healthier because they are all elite players in the prime of their career. The speed and vision of these players often allows them to navigate the game without being hit with the same frequency or magnitude as other players. Those in the next echelon of ice-time often include older players whose bodies have worn down over the course of a long career, or role players who are expected to do more of the physically natured ‘dirty work’. When these differences were accounted for in an age-matched analysis of 86 high school hockey players, time on ice per game was the strongest predictor of games lost due to injury (See Chapter 1 reference (51)). These data support the inherent knowledge that limiting exposure time minimizes the potential for harm to occur.

Table (Prologue). Games played according to NHL ice time

Season	2013-2014		2011-2012		2010-2011		2009-2010		2008-2009	
min/game	>19	<19	>19	<19	>19	<19	>19	<19	>19	<19
Mean	73	75	75	71	72	75	77	74	77	74
SD	12	8	11	13	14	9	7	10	10	9

Number of games played for those individuals averaging greater than or less than 19 minutes per game in the last 5 seasons. SD = standard deviation. (NHL.com)

In the case of the Kings and Rangers, only one of the eight full-time centres between the two teams played over 19 minutes of ice-time per game on average (NHL.com). It appears that not only did this distribution of talent and consequent ice-time help these teams succeed on the ice, it also kept them relatively healthy throughout the regular season and playoffs. The Kings and Rangers combined for a total of 164 regular season and 41 playoff games with four centres apiece (NHL.com). The Kings lost just 14 man-games to injury during the regular season (out of a possible 328) and zero in the playoffs (out of a possible 104) (NHL.com). The Rangers were even healthier, losing just *one* player for *one* game out of 328 regular season man-games, and only three man-games lost out of 100 playoff games (NHL.com). One of those playoff games missed was due to a broken jaw sustained from an illegal check, which was rewarded with a suspension to the offender (See Chapter 1 reference (56)). Of the 14 man-games lost by the Kings during the regular season, ten of those were the result of a leg injury to one player, who averages just less than 19 minutes of ice-time per game (NHL.com). Interestingly, and perhaps not coincidentally, that missed time was directly after an October 30th game against the San Jose Sharks, in which he played over 23 minutes (See Chapter 1 reference (57)). To put this astonishing health into perspective, these two teams combined for only 18 man-games lost out of a possible 860 (NHL.com). Based on the league average, the expected number of man-games lost at that position between the two teams would actually be 80 (NHL.com).

While circumstance is undoubtedly a factor with regards to the frequency of injury, the top eight centres in ice-time per game league-wide have combined to total more than the 15 games lost between the eight centres from these two teams in each of the last 15 full regular seasons (NHL.com). It is evident from these collective data that limiting exposure to gameplay has a protective effect on the players. What is less clear, however, is whether the decreased injury rate seen amongst players who play less is due to simply not playing, or if the fatigue caused by playing increases the susceptibility to injury.

CHAPTER 1 – LITERATURE REVIEW

1.1 Fatigue and Injury – The problem

Evidence from studies of other sports suggests that fatigue is both a perceived and an actual risk for injury during play. High school ice-hockey players who scored high for preseason and midseason perceived fatigue, were more likely to sustain an injury during the season (51). Similarly, when asked about their injuries, Chinese basketball players reported that they were fatigued at the point of injury and believe this to be a factor (32). Professional soccer players also cite fatigue as a risk factor for injury, behind only previous injury as a greater marker of risk (37). It turns out that these athletes are correct, but fatigue may actually be riskier than they think! In the aforementioned high school hockey study, ice time per game was the number one predictor of injury over the course of the season, while previous injury was not a significant factor (51). As it turns out, fatigue is not only a risk factor for these sports, but potentially all sports. Soccer (16), rugby (25, 26, 29), badminton (19), volleyball (5), baseball (43), and basketball (39) players, as well as gymnasts (18) and ballet dancers (33), were all more susceptible at the later stages of competition or practice, suggesting that injury risk is correlated with exposure. Moreover, when compared to male hockey players, women show a disproportionate percentage of injuries occurring in the second period (33.98% for men versus 51.72% for women) (49). The authors suggest that this increased injury rate in the second period of the women's game is due to fatigue, as there is no rink flooding in between the first and second periods, and consequently, no rest time (49). Indeed, there seems to be a relationship between fatigue and injury occurrence across all sports and even in animal models, as fatigue can lead to injury of racehorses (34).

The effects of fatigue on the incidence of injury are neither negligible nor acute. A prime example would include athletes who garner the most attention with regards to cumulative fatigue and injury: baseball pitchers. A baseball reporter for Sports Illustrated has actually developed a 'system' that will indicate pitchers who are at risk for injury (55). The pitchers who are named on this list are all under the age of 25 and pitched at least 30 innings more in the past year than they did in the year previous (55). In keeping with the same thought, some Major League Baseball teams have set unofficial innings-pitched limits for young pitchers in hopes of keeping them healthy. One such example is the Washington Nationals' Stephen Strasburg, who was shut down for the season after 28 starts in 2012 (8). This is a controversial topic among those involved with the game, but a study of youth baseball pitchers has shown that fatigue is a definite risk factor for injury (43). In this survey study, injured pitchers reported more games played, over a longer season, with more innings per game, pitches per game, pitches per year and pregame warm-up pitches (43). It is important to note that baseball pitchers are also a model example in the "fatigue" versus "exposure" question. Obviously, an athlete who plays more (more time, more games, etc.), exposes him or herself to increased risk of injury (i.e. you will not be injured in sport if you are not playing). However, when you examine contact sports such as American football or English football (soccer), increased playing time exposes you to a greater number of player contacts and therefore potential injury by this mechanism. In contrast, baseball pitchers are little contacted by the opposing players or even the ball for that matter. Consequently, increased injury with added exposure in baseball pitchers is almost exclusively a result of physiological fatigue of the joints, bones, ligaments, muscle, etc. and shows the importance of at least monitoring if not limiting playing time for the athlete's health and team's success.

Moreover, a study of professional soccer players over 11 seasons indicated that injury rates were higher in a match following four days or less of recovery than they were for matches following six days or more of recovery (6). More injuries also occurred when matches were grouped closely together (6). Both situations result in an increase in hamstring muscle, quadriceps muscle and joint ligament injuries (6). Moreover, rugby players have also been shown to be more susceptible to injury when training or competition schedule is condensed (24), though another study would suggest that they are not more susceptible to injury *per se*, but rather they are more susceptible to *severe* injury with a heavy workload (11). In any case, it is clear that in terms of the overall health and safety of these athletes, limiting fatigue (with respect to the aforementioned studies, by increasing recovery time) is crucial.

1.2 What is Fatigue?

It is still unclear, however, *how* fatigue affects injury occurrence, or for that matter, *what* fatigue is to begin with. The commonly accepted definition of fatigue in sport or exercise physiology is as follows:

> "extreme tiredness resulting from mental or physical exertion or illness; a reduction in the efficiency of a muscle or organ after prolonged activity" (20).

However, a simple definition of fatigue, often times does not suffice in practice. Abbiss and Laursen (2005) note that among scientists, there are several interrelated models that could be used to explain exercise related fatigue (1). These models include: decrements in cardiovascular function and the ability to supply the body with oxygen rich blood while simultaneously removing metabolic by products (Cardiovascular/Anaerobic model); an inability to meet working muscle energy demands (Energy Supply model); failures in excitation-contraction coupling (Neuromuscular model); micro/macro trauma to the myofibrillar structure and muscle as a whole (Muscle Trauma model); reduced efficiency of motion with prolonged or strenuous exercise (Biomechanical model); competition for the increased demands of thermoregulation and cardiac output to working tissues as well as the body's self-protection from increased temperature (Thermoregulation model); decreased motivation to continue activity (Psychological/Motivational model); and a more overarching whole body safety switch against over exertion (Central Governor model) (1). It is most likely that fatigue is a product of several of these models and that it will differ depending on the degree of universally accepted FITT principles (i.e. dose) of exercise: the Frequency, Intensity, Time/Duration and Type/Mode of exercise. Nonetheless, the central governor model has received much attention in the recent literature.

With respect to the central governor model, to facilitate movement, the brain sends an efferent (away from central command) signal to the effector muscle (initiating movement), which in turn sends an afferent (toward central command) feedback signal to the brain. This reciprocal interaction between the brain and effector muscles can be disrupted along the efferent or afferent pathways, as well as the two terminals themselves. If fatigue is the result of disruptions at the brain or in the spinal cord, it is referred to as central fatigue. While not entirely understood due to the complexity of fatigue, central mechanisms, as noted, have been proposed as a major factor in fatigue occurrence (42). One component of central fatigue may be elevations in concentrations of serotonin in the brain (which occurs during exercise) that are detrimental to muscular activation because the serotonin binds to receptors at the beginning of the motor neuron and inhibits action potential propagation (13). Regardless, central fatigue is proposed to result in a greater perceived effort required to maintain the same work output.

All of the proposed models of fatigue are detrimental to the function of muscle since in order to perform, a muscle requires proper structure, proper signals and proper fuel. Upon the central nervous system (CNS) sending a signal to effector neurons to contract, an electrical signal then propagates along motor neuron axons to the terminal where it will meet the muscle at the neuromuscular junction. It is at the axon terminal where the electrical signal triggers the release of acetylcholine (ACh), a chemical messenger that binds to a ligand-sensing channel on the muscle membrane and causes the opening of Na+ channels. Once these channels are open, a new electrical action potential spreads via transverse tubules on the surface of the muscle. However, eventually, the Na^+ or K^+ chemical gradients may be modified, or metabolic byproducts like hydrogen may accumulate thereby changing the electrical gradient of the muscle cell (21, 27). The effects of either scenario on the electrochemical gradient required to propagate an action potential would result in the muscle cell requiring a stronger stimulus in order to fully contract. Accordingly, if the neurons involved in transmitting that stimulus are similarly compromised to the point where they cannot send stronger signals, the muscular output will be reduced.

In athletics, both central and peripheral mechanisms of fatigue may contribute to the onset of injury separately or in unison. For instance, tackling form is known to be compromised in a fatigued individual (23), or, as suggested in a study of volleyball players, a decline in joint position sense (i.e. proprioception) seen in fatigued athletes may cause injury (48). Either case could be explained by central or peripheral fatigue, though typically both are present during intense athletic competition. While it is nearly impossible to gauge the extent of each contribution, what can be observed tangibly is the extent to which fatigue as a whole alters the normal function of an athletic movement or response.

1.3 Fatigue and Kinematics

The coordination of athletic motion is altered as a result of fatigue. Variation in the biomechanics of a performed task requiring a high degree of stability is undoubtedly dangerous. These changes in kinematics, may not only effect the fatigued athlete since it could be theorized that an athlete who has lost the ability to "move" in an optimal fashion, may set him or herself up for collisions with other athletes who may be injured as a result. One task common to both athletics and laboratory tests of fatigue is the jump landing. Whether an athlete is jumping in the air to catch a ball, score a goal off a corner kick or dismount after a gymnastics routine, landing a jump is an important aspect of the task and carries with it some inherent risk. Any flaw in the coordination of responsible muscles could result in catastrophic failure of the ankle or knee joint. In a research setting, experimenters commonly find that fatigue changes the kinematics of that landing in a way that leaves the performer more vulnerable to knee injury (7, 44, 46, 50). Specifically, fatigue results in landing with a more erect hip (46, 50) and knee postures (7, 46), which result in increased hip loading, ankle loading and knee shear force (50). Fatigue may also lead to knee joint instability (44). Likewise, kinematic changes have been observed in baseball pitchers between the first and last inning, which suggests that this may lead to injury (41). As a result of these increased loads and instability, the related structures are more likely to fail, thereby leading to injury, though these lab results may not translate to on-field outcomes.

1.4 Competitiveness and Motivation

While lab-based fatigue research may be our best window into the effect of fatigue on joint kinematics during athletics, it is not without flaw, as the laboratory and field of play are two very different environments. Fatigue may alter the kinematics of a movement in the lab setting, but during an actual athletic event, an athlete may be able to maintain proper form. For example, motivation or competitiveness are not easily replicated in a lab setting but may result in an athlete taking more risky/vulnerable action (e.g. diving for a ball out of bounds, jumping and stretching to catch a pass that is thrown too high, etc.) in spite of fatigue. Ironically, the drive to succeed may put the athlete at risk in other ways. Competitiveness would likely increase in the later stages of the game, since in many instances, this is where the outcome is potentially on the line. Conversely, a player involved late in a blowout game where the outcome has long-since been determined, could lose motivation to perform or even be taken out of competition by their coach. This could result in a complacent athlete being hit off-guard or not bracing properly for impact or inexperienced/less fit athletes being placed in harm's way. Without consideration of this behaviour, a researcher may falsely attribute an elevated incidence of injury in the second half of games to fatigue, when it should actually be attributed to a change in motivation or competitive behaviour. Fortunately, periods of relatively high (second half) versus low (first half) in-game competitiveness can be paralleled with similar situations throughout the playing season. Specifically, preseason, regular season and post season would theoretically increase in competitiveness respectively. Tracking injury rate during each of these segments would help to shed light on this potential confound. Competitiveness, however, may lead to elevated tension due to the accumulation of numerous battles between opposing players throughout a game. This could lead to an increase in aggressive or violent acts that may result in more injuries later in the game, though this could be tracked by examining injury cause.

Another potential confound is the difference in game environment as the game progresses. While indoor sports like basketball and ice hockey have relatively consistent environments from period to period, outdoor sports may change considerably. In Major League Baseball, a grounds crew comes to the field in between innings to help maintain the integrity of the playing surface, however, gameplay results in field damage in other sports, though barring major damage to the field, there is no maintenance during the game. Ruts caused by cut steps, or even accumulation of rainwater could result in an unsafe playing field later in a game, leading to an increased rate of injury. In order to attribute an increase in injury frequency to fatigue, this possibility must be controlled for. Examination across both indoor and outdoor sports provides a method to control for environmental factors.

It is unknown what these controls might yield, however, there are some differences observed in field research that cannot be accounted for by motivation, violence or environment. For example, during soccer, the hamstrings have been shown to fatigue at a faster rate than the quadriceps (16, 28). The resultant imbalance in the strength of the leg muscles responsible for running has been proposed as a cause for the high frequency of hamstring strains late in soccer matches (16, 28). An increase in injury frequency of a fatigued muscle versus a relatively non-fatigued muscle cannot be explained by cognitive factors, as these individual muscles are not more competitive than the other, nor are they more susceptible to opposing violence. Nor too can this difference be accounted for by environment, as both the quadriceps and hamstrings are running on the same ground and, for example, in a hot environment dehydration would affect both neuromuscular units similarly.

As such, some component of fatigue appears to be the most likely cause of elevated injury rate later in games.

1.5 Sex Differences in Fatigue

Given that a relationship has been suggested between fatigue and injury, and that there are differences in fatigue's effect on either sex, it is reasonable to suggest that there may be sex differences in fatigue's effect on injury rate. Laboratory research does support this claim, as there is evidence to suggest that fatigue alters kinematics of coordinated tasks to a greater extent in women than in men. For example, in jump landing, the extraneous movements described above are greater in women than their male counterparts following a fatiguing protocol (38). This is potentially a consequence of less muscle mass stabilizing the surrounding joints. Additionally, a fatiguing protocol results in a greater percentage of strength loss in the knee extensor muscles of women than men (40). However, women have been shown to be more resistant to muscular fatigue than men (22, 30, 35). This would intuitively negate any difference in injury susceptibility per game-time, yet, women typically have less muscle mass than men. Consequently, male joints have more muscle (albeit fatigued muscle) fighting against inappropriate movement. Therefore, females' increased fatigue resistance may not translate to injury resistance. In theory, if sloppy movements were the mechanism by which fatigue could be measured as an indicator of injury risk, this additional movement would lead to proportionately more non-contact injuries later in competition for women as long as the playing time was evenly matched. It is not yet known whether this is the case, though it appears that women are more susceptible to injury in athletics (2, 45).

1.6 Additional Mechanisms of Injury in Athletics

As noted earlier, some injuries are simply unpredictable. While one could argue that a pitcher who is not fatigued would be alert enough to snare a line drive directed at his head, some injuries are more likely the result of unfortunate circumstances. For instance, in badminton, a ruptured Achilles' tendon is a more common occurrence late in games and is thereby attributable to fatigue (19), whereas in ice hockey, a severed Achilles' tendon due to rare contact from a skate blade is not. Ideally, the exact mechanism of each injury would be provided in order to discern which injuries should be excluded. In lieu of such information, a large sample size should be sufficient in order to negate chance injuries.

While many injuries would occur regardless of the effect of fatigue, they should be expected to happen at the same rate throughout a game, practice or season. Using that logic, any spike in occurrence may be due to other factors of which fatigue may be one. Non-contact injuries are, by definition, caused by some failure of the body to execute a movement properly. As indicated earlier, fatigue often leads to improper mechanics during athletics (12, 31), and therefore could be a contributor to non-contact injuries. Fatigue is less likely to be a factor in contact injuries like lacerations or contusions, though these are typically not significant injuries. Other contact injuries, such as broken bones, torn ligaments or concussions may be primarily circumstantial, however, fatigue or dehydration may affect the circumstances an athlete finds him or herself in (4, 14, 47, 54).

To that end, fatigue has been found to effect rate of concussion in ice hockey, as ice-time per game was a significant predictor of concussion in NHL players during the 2001-2002 season, where players averaging over the league-wide median in ice-time per game were almost twice as likely to sustain a concussion (16 concussions below median versus 29 concussions above median) (52). This could be due to the effects of fatigue, causing players to put themselves in more vulnerable positions or not react as quickly to danger. A separate, but not unrelated explanation involves dehydration, which commonly occurs in sport and is actually proposed to play a role in the development of fatigue during physical activity (36).

As core temperature increases as a result of the catabolic reactions required for exercise, the sweat mechanism is activated in an attempt to cool down. While water loss due to sweat can obviously be negated by water entering the body by drinking, studies have shown that athletes do not rehydrate to the appropriate levels during events and are therefore, *de*hydrated (3, 9, 53). In fact, the extent of this dehydration has been shown to be approximately 2-3% during competition in team sports (10), where individuals are also vulnerable to concussion (15). Dehydration of this magnitude has been shown to be associated with a roughly 10% reduction in cerebrospinal fluid (CSF) volumes (17). This liquid serves to cushion the brain during head accelerations that would otherwise cause the brain to impact with the skull (17). Perhaps the dissipation of this protective barrier plays some role in the increased rate of concussions seen in fatigued athletes. Either cognitive deficits as a result of fatigue and dehydration, or the effects of dehydration on the volume of movement-resistant fluids could viably lead to more concussions in a fatigued state.

The notion that cognitive deficits caused by fatigue could increase the likelihood of athletes placing themselves in a vulnerable position should translate to other forms of contact injuries as well. In fact, a study on rugby players showed that tackling form is compromised while in a fatigued state (23). Since tackling form is taught in order to protect the player as well as the opponent he is tackling, it would make sense that this leads to more injuries. Furthermore, a separate study of rugby players showed that an increased training load led to more contact injuries, and that the relationship was similar to that of non-contact injuries (24). As such, it is reasonable to suspect that fatigue will increase the incidence of all contact injuries. If, however, concussions increase substantially more than other injuries, some other variable associated with fatigue and concussions, but not other injuries, would likely be the cause (for example, dehydration perhaps).

As fatigue is dependent on exertion, the stance taken in this thesis will be that those injuries whose rates are susceptible to fatigue will occur more frequently as the game progresses, resulting in the total number of injuries to be higher late in the game. Moreover, since women show an exaggerated vulnerability to fatigue-related kinematic changes, these effects should be more prevalent in female athletes than men.

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CHAPTER 2 – MANUSCRIPT

2.1 General Introduction

Coaches limit playing time of their star athletes in meaningless (i.e. immediate result likely determined or post season success already determined) games in an attempt to “save” these players for important competition. A prominent example of this is Major League Baseball (MLB) pitchers who are monitored closely for number of pitches and within whom strict pitch limits are usually placed on young and high valued players. Intuitively, this makes sense since competition undoubtedly increases the wear and tear on the human organism. Specifically with respect to baseball, injured pitchers reported more games played, over a longer season, with more innings per game, pitches per game, pitches per year and pregame warm-up pitches (41). In fact, it has been shown that playing time is a greater predictor of injury over the course of the season than even previous injury in other sports such as ice hockey (50) and that exposure is a significant risk factor for injury in soccer (7), rugby (17, 18, 24), badminton (12), volleyball (4), baseball (41), basketball (39), gymnastics (11) and ballet (30). Consequently, the overwhelming data confirms simple intuition that injury risk is correlated with exposure.

What is still unclear, however, is *how* fatigue affects injury occurrence. Fatigue is commonly defined as, “extreme tiredness resulting from mental or physical exertion or illness; a reduction in the efficiency of a muscle or organ after prolonged activity”(13). However, a simple definition of fatigue often does not suffice in practice. Abbiss and Laursen (2005) note that among scientists, there are several interrelated models that could be used to explain exercise related fatigue (1). These models include: decrements in cardiovascular function and the ability to supply the body with oxygen rich blood while simultaneously removing metabolic by products; an inability to meet working muscle energy demands; failures in excitation-contraction coupling; micro/macro trauma to the myofibrillar structure and muscle as a whole; reduced efficiency of motion with prolonged or strenuous exercise; competition for the increased demands of thermoregulation and cardiac output to working tissues as well as the body's self-protection from increased temperature; decreased motivation to continue activity; and a more overarching whole body safety switch against over exertion (1). It is most likely that fatigue is a product of several of these models and that it will differ depending on the FITT principles (i.e. dose) of exercise: the Frequency, Intensity, Time/Duration and Type/Mode of the activity. Nonetheless, in athletics, both central and peripheral mechanisms of fatigue may contribute to the onset of injury separately or in unison. For instance, tackling form is known to be compromised in a fatigued individual (16), or, as suggested in a study of volleyball players, a decline in joint position sense (i.e. proprioception) seen in fatigued athletes (47). Either case could be explained by central or peripheral fatigue, though typically both are present during intense athletic competition. Moreover, the actual risk for injury is also observed by an increased perceived significance of fatigue in injury risk in many athletes (29)(37) and that athletes who score high for preseason and midseason perceived fatigue are more likely to sustain an injury during the season (50). Indeed, improper training practices (i.e. reduced recovery after injury, high intensity training, multiple races, etc.) associated with fatigue increase injury occurrence even in animals (racehorses) (35).

Nonetheless, just as fatigue is multifaceted, so is the term injury. For example, the potential for collision is likely similar at all times of a football game and therefore injuries associated with impact (e.g. contusions, concussions, lacerations, fractures, etc.) might show little association with playing time in comparison to injuries such as muscle spasms which are more numerous later in matches and/or in extreme temperatures when the physiological detriment of dehydration is most likely to occur. However, even though the former injury type (i.e. those associated with impact) may be primarily circumstantial, fatigue or dehydration may affect the circumstances an athlete finds him or herself in (3, 6, 46, 53) and therefore indirectly increase injury risk. It is not fully known, however, to what degree the aforementioned injuries (and others) differ with respect to playing time. However, the tissues that are more fatigable (e.g. muscle) should show a greater increase in injury frequency later in games than relatively non-fatigueable tissues like bone. Concussion rate may also increase later in games if there is some relationship between concussion susceptibility and fatigue or dehydration, which is expected due to the depletion of CSF during dehydration (18).

Finally, men and women not only differ in susceptibility to certain types of injury (14), they also differ with respect to fatigue. Women appear to be more resistant to muscular fatigue than men (15, 25, 36), but men have more muscle mass and appear less susceptible to altered kinematics during fatiguing situations (38). Therefore, females' increased fatigue resistance may not translate to injury resistance. It is not yet known whether this is the case, though it appears that women are more susceptible to many types of injury in athletics (2, 43).

Understanding injury risk is important to understanding how best to modify training and game time play from an athlete or coaches perspective as well as how to host competition from an administrative standpoint to ensure the health of participants.

2.2 Purpose

To determine whether injury rate increases over the course of competition and whether sex differences exist in this relationship.

2.3 Hypotheses

The proposed study has been designed to test the hypotheses that:

1. In all sports, a greater frequency of injuries will occur as gameplay progresses.
2. This result will be a function of increased muscular, joint and head injuries later in games.
3. These results will be more pronounced in women.

2.4 Methods

2.4.1 Datalys and NCAA Injury Surveillance System (ISS)

To test these hypotheses, National Collegiate Athletics Association (NCAA) injury surveillance data were collected from the Datalys Center for Sports Injury Research and Prevention (hereafter referred to as Datalys). Datalys is a non-profit organization co-founded in 2009 by the NCAA, American College of Sports Medicine (ACSM) and BioCrossroads, in order to help understand and prevent sports injuries. While this research originated in 1982 with the NCAA Injury Surveillance System (ISS) (8, 26), Datalys later took on control of the process (Datalyscenter.org).

Datalys relies on 250 volunteering NCAA schools to send two-page injury reports related to selected sports (8, 26). The level of interest from each school in a particular sport determines the sports each school is selected to report on. For example, a school that lists men's football (fall), men's basketball (winter) and women's lacrosse (spring) as its primary sports, would be included in the data pool for those sports, as well as some of the other sports that it listed as secondary. The school has the option to reselect its primary or secondary sport or even opt out each year. Only institutions that submit data for at least 70% of the weeks are included in the reports (8, 26). In return for participating in data collection, each school is granted the raw data at the end of the year, as well as a summary of trends observed in the data to help understand and prevent injuries in sport (8, 26). The deterministic sampling used by Datalys provides a layer of confidentiality because only schools selected for a certain data pool will be providing data (8, 26). That is to say, if a university has a men's lacrosse team, but does not select that as a primary sport, and is not selected by Datalys from the schools that provide men's lacrosse as a secondary sport, it will not provide data for that sport. Confidentiality is further ensured by not granting access to any information that may help to identify an athlete (i.e., game day, team, location, etc.).

NCAA athletic trainers volunteer to send detailed injury reports to Datalys, via an "Export Engine", thereby gathering data in one central location (Datalyscenter.org). To qualify as an injury, the ISS states that it must have:

1. occurred as a result of participation in organized intercollegiate practice or competition *and*

2. required medical attention by a team certified athletic trainer or physician, *and*

3. resulted in restriction of the student-athlete's performance or participation for one or more calendar days beyond the day of injury (8).

Upon entry into the export engine, the athletic trainers record data regarding a number of variables, including data representing the exposure of the athlete, as well as the injury itself (8). Over a span of 16 years, the ISS accumulated 182 000 useable injury records for an average of over 11 thousand per year (8). Access to such a thorough and extensive database is not granted without meeting proper protocol. Upon Research Ethics Board approval at the University of Windsor (appendix A), as well as the completion of a signed application indicating the terms of data release (appendix B) the project received approval from internal evaluation at the Datalys Center (appendix C). Datalys then received final permission from the NCAA to grant injury surveillance data to this project (appendix D). All three approvals were necessary to obtain this information.

Data from 2004/2005 to 2008/2009 in men's football, soccer, basketball, lacrosse and ice hockey, as well as women's soccer, basketball, lacrosse, ice hockey and field hockey were analyzed. These sports were chosen because they are major collegiate athletics and except in the case of football and field hockey, have both male and female versions of the sport. Women's field hockey was chosen to balance with Men's football, however, these sports are not the same and consequently, in sex comparisons across sports, football and field hockey were excluded in order to control for type of sport.

2.4.2 Categorization of Data

The data provided for each injury included exposure variables (academic year, sport, season segment, competition type and playing surface) as well as injury variables (player activity at time of injury, athlete's position at time of injury, game time, basic and specific mechanism of injury, time lost, outcome, injury type, and whether it was a recurring injury). The Datalys reporting system also allows therapists the ability to code injuries into the various types. Table 2.1 lists these coded injuries in subgroups used for later data analysis within the current study.

Table 2.1. Subgrouping of injuries by type and repetitiveness.

Injury Type	Subgroup for Analysis	Acute/Chronic
Concussion/neurotrama	Concussion	Acute
Effusion	Inflammation/Swelling	Acute
Inflammation	Inflammation/Swelling	Acute
Infection	Inflammation/Swelling	Chronic
Synovitis	Joint/ligament/cartilage	Chronic
Sprain	Sprain	Acute
Dislocation	Joint/ligament/cartilage	Acute
Subluxation	Joint/ligament/cartilage	Acute
Instability	Joint/ligament/cartilage	Both
Bursitis	Joint/ligament/cartilage	Acute
Arthritis/chondromalcia	Joint/ligament/cartilage	Chronic
Hypomobility	Joint/ligament/cartilage	Both
Cartilage Injury	Joint/ligament/cartilage	Acute
Capsulitis	Joint/ligament/cartilage	Chronic
Impingement	Joint/ligament/cartilage	Chronic
Osteochondritis	Joint/Ligament/cartilage	Both
Strain	Strain	Acute
Spasm/Cramp	Spasm/Cramp	Acute
Tendinosis	Muscular	Chronic
Compartment Syndrome	Muscular	Not Applicable
Myositis ossifications	Muscular	Not Applicable
Plantar Fasciitis	Other	Chronic
Reflex Sympathetic Dystrophy	Other	Not Applicable
Neuroma	Other	Not Applicable
Nerve Injury	Other	Acute
Neoplasm	Other	Chronic
Organ Injury	Other	Acute
Overuse	Other	Chronic
Unknown	Other	Unknown
Miscellaneous	Other	Unknown
Other	Other	Unknown
Fracture/Avulsion	Fracture	Acute
Fracture (Stress)	Fracture	Chronic
Growth Plate (epiphyseal) injury	Fracture	Not Applicable
Necrosis (avascular)	Fracture	Not Applicable
Exostosis	Fracture	Chronic
Osteomyelitis	Fracture	Not applicable
Disc Injury	Other	Acute

Contusion	Cutaneous	Acute
Laceration	Cutaneous	Acute
Abrasion	Cutaneous	Acute
Cysts	Other	Not Applicable
Blisters	Other	Acute
Blood Vessel Injury (e.g. entrapment)	Other	Chronic

Playing time was divided into halves that could be standardized across sports to account for game structure differences between sports. To that end, injuries that occurred during the warm-up, overtime or in practice were not included in analyses. Table 2.2 indicates the total number of injuries and those that were excluded because they fit into one of the aforementioned circumstances.

Table 2.2

Event Type/Game Time	# of Injuries Pre-Season	# of Injuries Regular Season	# of Injuries Post-Season	Subtotal
Practice	12973	8787	511	22271
Warm up	11	274	11	296
Regulation time	363	12388	473	**13224**
Overtime	3	119	8	130
Game-time unknown	67	1986	60	2113
Total	13417	23554	1063	38034

Analyses for half/period were only performed on injuries that occurred during regulation time and consequently, 13224 injuries (bolded in table) were used to develop subgroups of injury type. However, for analysis of season, all injuries were included.

This study proposed to examine changes in the rates of acute injuries while fatigued. To that end, injuries deemed to be chronic were not included in these analyses because they present before acute fatigue. Superficial injuries such as abrasions, contusions, and lacerations are likely due purely to the nature of the sport, with no effect of fatigue, however, given that movement is modified and less efficient with fatigue (noted above), these types of injuries could be more common later in games. These injuries may also be linked to other injuries that *are* directly tied to fatigue and were therefore included. Classifications of the remaining injuries were stratified according to similarity of the injury and specifically broken down into the following eight categories: strain, sprain, cutaneous, fracture, concussion, joint, spasm/cramp and other. Table 2.3 indicates which injuries were included in the analyses and which category they were grouped into.

Table 2.3. Categorization of Injuries

Category	**Associated Injuries**	**# of Injuries**
Strain	Strain, Tear	1564
Sprain	Sprain	4768
Cutaneous	Abrasion, Contusion, Laceration	2685
Fracture	Fracture	772
Concussion	Concussion	1356
Joint	Cartilage Injury, Subluxation, Bursitis, Tendinosis, Capsulitis, Dislocation	1135
Spasm/Cramp	Spasm, Cramp	165
Other	Nerve Injury, Unknown, Miscellaneous, Other, Disc Injury, Effusion, Plantar Fasciitis, Osteochondritis, Inflammation, Compartment Syndrome, Cysts, Arthritis, Impingement, Neuroma, Organ Injury, Myosytis Ossificans, Overuse, Infection, Blisters, Missing, Growth Plate Injury, Necrosis, Exostosis	779
Total		**13224**

Categorization and number of injuries included in analysis of injuries by half during competition.

In the case of ice hockey, the second period was removed from the across sport analyses and third period injuries were grouped into the 'second half' variable. However, when analyzed separately, all three periods were examined. Football was also taken out of the across sport analyses, but for a different reason. The inherent violence of football was deemed to be a confounding factor that would mask the effects of fatigue on injury rate. For individual analysis, football remained divided into quarters in order to further investigate the effects of fatigue on injury rate.

2.4.3 Statistical Analyses

Frequency counts, and tests of association (goodness of fit) were performed using chi-square (χ^2) analysis directly or for tests of independence using the crosstabs function of IBM SPSS Statistics version 21 for data with multiple columns and rows. In order to test hypothesis 1, that the frequency of injuries occurs later in games, a chi-square test was performed with all sports grouped together and using first half and second half as categories with the variable of half. Subsequently, frequencies were performed on separate data by injury type, game time, sport, season and sex. A chi-square statistic in the critical region for a p-value less than 0.05 was considered significant for all analyses. For any 2x2 table frequency analysis with a significant chi-square, a Mantel-Haenszel Test for odds ratios and 95% confidence limits was calculated and reported. Specifically, any sex by half analysis using all sports, within sport or within injury produced odds ratios and 95% confidence limits.

In the final analysis, injuries by season are reported as injury rate. Injury rate was calculated using athletic exposures and the aforementioned injury data. Athletic exposures were defined in Datalys as "1 student–athlete participating in 1 NCAA-sanctioned practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of the time associated with that participation" (26). It is important to note that for competition exposures, only athletes who received playing time in the competition were included in the dataset according to the Datalys reporting system (8,26). The number of athletic exposures and the number of injuries during those segments was used to calculate the number of injuries per every 1000 exposures, a standardized format of injury rate reporting.

2.5 Results

2.5.1 Analysis of all injuries

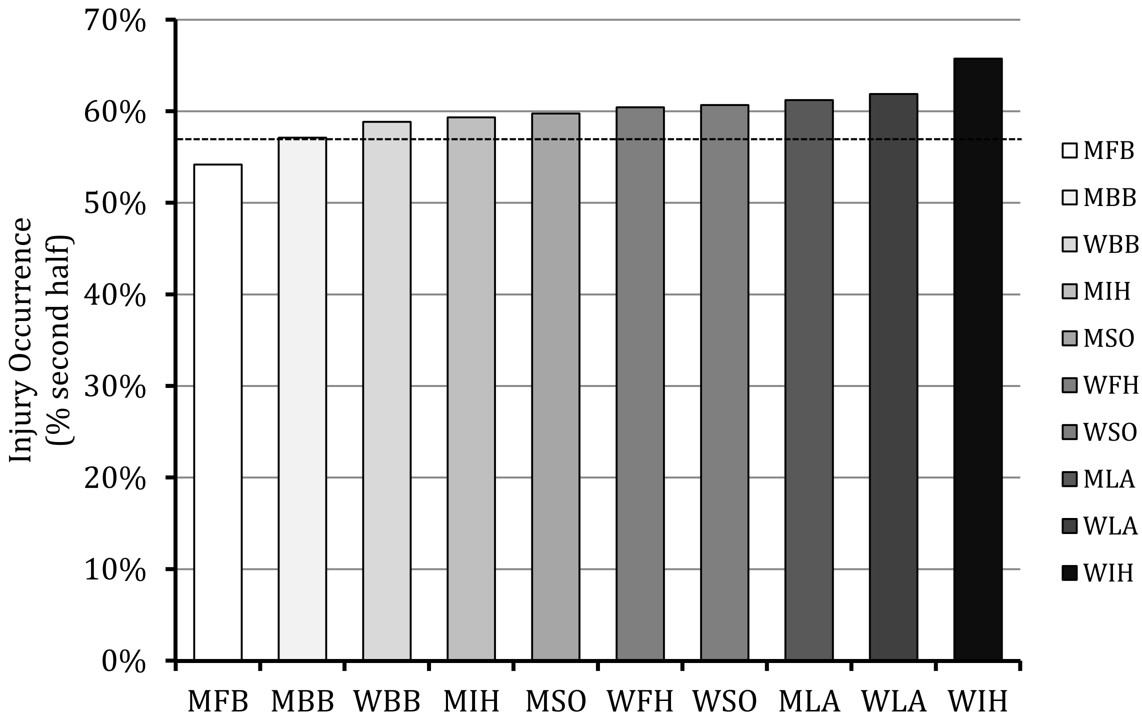
A total of 13224 injuries from the 2004/2005 – 2008/2009 athletic seasons were obtained (Table 2.4). For analysis of all injuries across all sports, second period injuries in both men's (n=275) and women's (n=55) ice hockey were eliminated and consequently, 12894 injuries were used in the comparison of all sports. A goodness of fit test (chi-square) revealed that there were significantly greater injuries of all causes later in games, $\chi^2(1) = 262.57$, $p<0.001$. Specifically, across all sports, 7367 injuries occurred in the second half (or third period), accounting for 57.1%, in total, of the 12894 total injuries examined. Figure 2.1 shows individual second half injury frequency by sport and sex.

Table 2.4. Total number of injuries used in primary analysis by sex and sport.

Sport	# of Injuries (Men)	# of Injuries (Women)	Total
Basketball	1166	1040	2206
Ice Hockey	725	163	888
Lacrosse	472	181	653
Soccer	1652	1630	3282
Field Hockey	n/a	278	278
Football	5917	n/a	5917
Total	9932	3292	**13224**

Note that there is no NCAA men's field hockey or women's football programs (n/a: not applicable).

Figure 2.1. Injury occurrence (% second half) by sex and sport



Percentage of all injuries occurring in the second half or last period of play in all sports. Across all sports, the dotted horizontal line represents the second half injury occurrence. MFB = men's football; MBB = men's basketball; WBB = women's basketball; MIH = men's ice hockey; WIH = women's ice hockey; MSO = men's soccer; WSO = women's soccer; WFH = women's field hockey; MLA = men's lacrosse; WLA = women's lacrosse.

2.5.2 Analysis of injuries by injury type and half

A significant chi-square was observed for injury type by half, $\chi^2(7) = 62.518$, $p<0.001$. There were a consistently higher number of injuries observed in the second half for all types of injuries except for fractures (Figure 2.2). Spasms and cramps occurred most often in the second half, as 64.2% of these injuries occurred in the later stage of the game. Spasms, concussions, 62.7%, cutaneous injuries, 60.7%, other, 59.2% and sprains, 57.3% appeared to occur more frequently than strains, 54.7%, joint injuries, 54.3% and fractures, 50.5% as occurring in the second half.

2.5.3 Analysis of injuries within injuries by sex and half

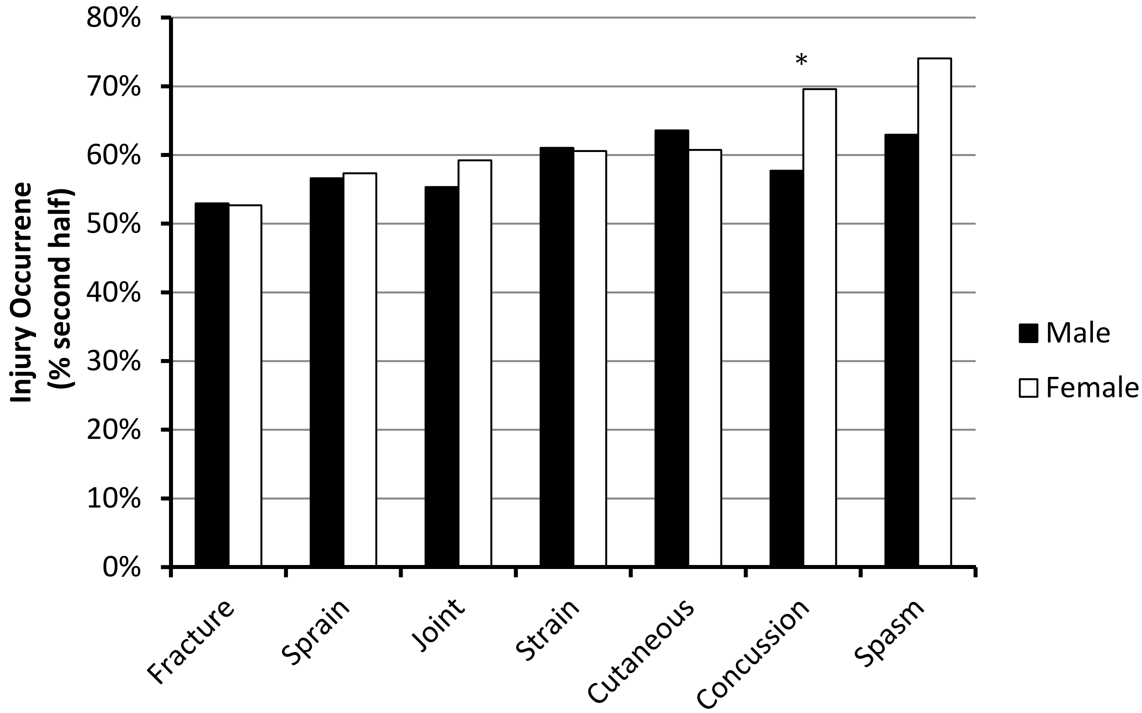
The relative frequency of injury was higher for women than men with respect to concussions, where in a separate analysis of all sports except football and field hockey (excluded for sex-matching purposes) it was revealed that 69.6% of all female concussions happened in the second half of games, whereas this figure was only 57.7% for male athletes (Figure 2.2, Table 2.5), $\chi^2(1) = 11.442$, $p<0.001$ (OR=1.676, 95% CI = 1.241, 2.262). Spasms and cramps also occurred disproportionately more in the second half for women (73.7%) than men (58.8%), however, this did not reach significance, $\chi^2(1) = 1.545$, $p=0.214$. There was no relationship observed between injury frequency by half and sex for sprains, strains, fractures or ‘other’ injuries, and was negligible in cutaneous and joint injuries (Table 2.5, $p>0.05$).

Table 2.5 Chi-square and odds ratio table for sex by half within injuries

Injury Category	χ^2	df	p	OR	95% CI LL	95% CI UL
Concussion	**11.442**	**1**	**0.001**	**1.676**	**1.241**	**2.262**
Spasm	1.545	1	0.214	1.681	0.739	3.823
Cutaneous	1.281	1	0.258	0.885	0.717	1.093
Joint	0.795	1	0.373	1.173	0.826	1.664
Sprain	0.120	1	0.729	1.030	0.870	1.220
Other	0.059	1	0.808	0.949	0.620	1.452
Strain	0.019	1	0.889	0.979	0.730	1.313
Fracture	0.003	1	0.956	1.011	0.672	1.523

Note that men's football and women's field hockey injuries were excluded since there could be no sex comparison in either case. Chi-square (χ^2) analysis in crosstabs was performed for 2 (male, female) x 2 (first half, second half) tables. Odds ratios represent the odds of injury in the second half for women relative to men. A significant chi-square and odds ratio with 1.000 outside of the 95% CI range is bolded.

Figure 2.2. Injury occurrence (% second half) by sex and injury type

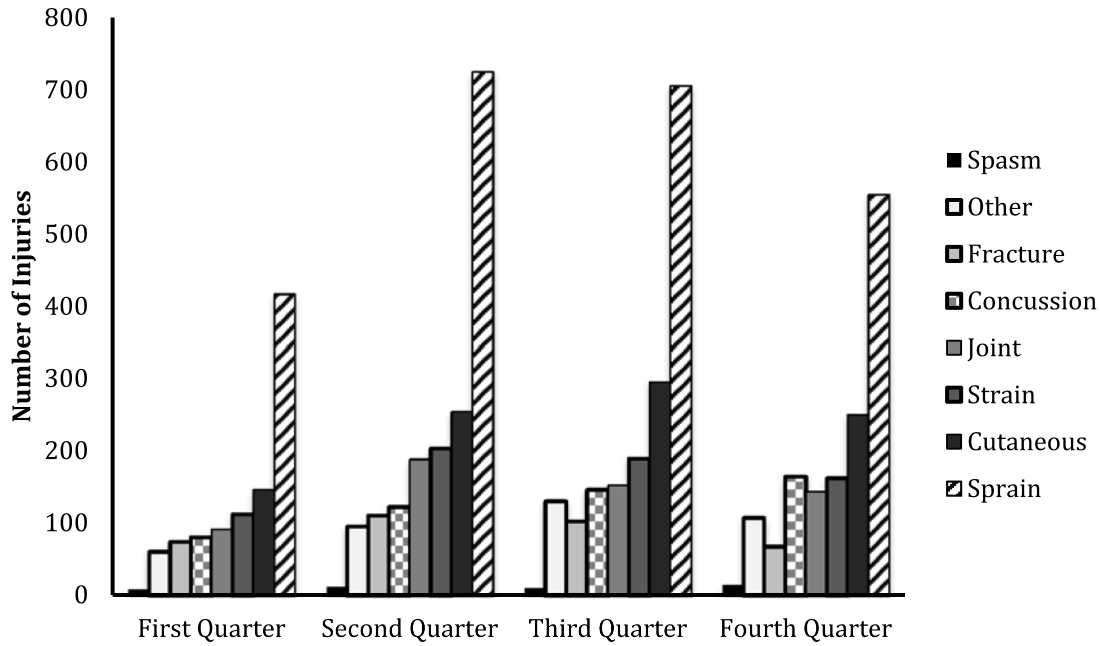


Percentage of injuries occurring in the second half for men and women by injury category. Note that chi-square analyses were performed in separate 2x2 crosstabs for each injury. * represents a significantly greater frequency in women versus men.

2.5.4 Analysis of injuries in Men's Football

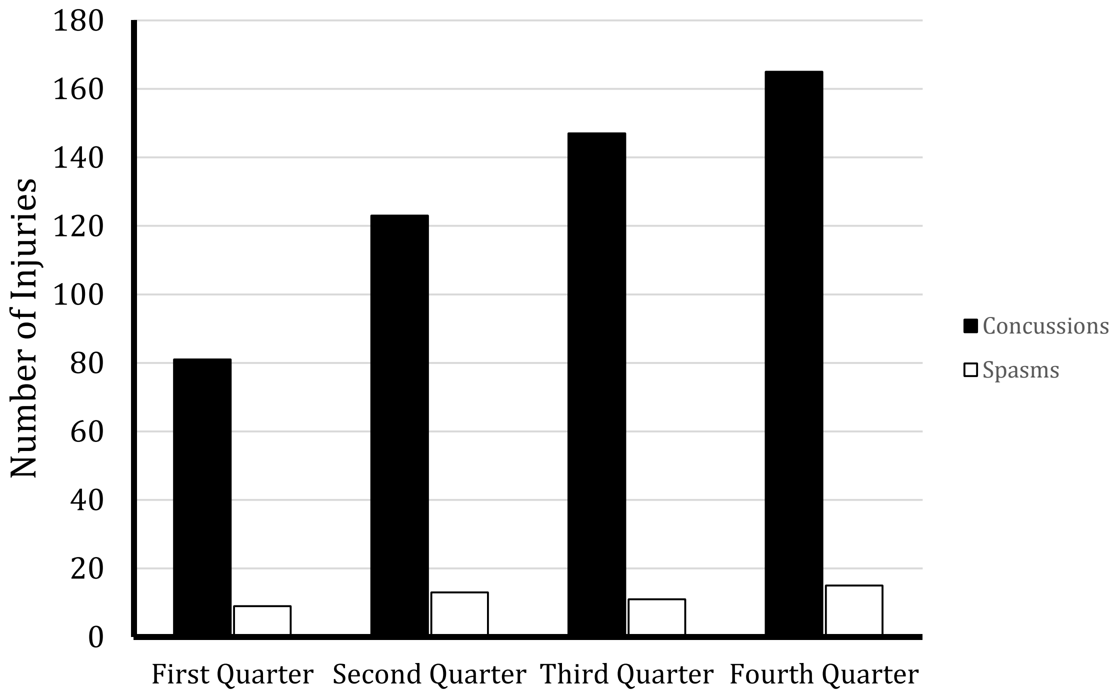
Frequency analysis of men's football revealed a significant chi-square (χ^2 (21) = 47.46, $p<0.001$) indicating that injury frequency within some injury types was not independent of quarter (Figure 2.3). Specifically, there was an inverse-U shaped pattern of injuries, where occurrence was highest in the second and third quarters, then reduced in the fourth quarter, though still higher than the first quarter. This observation was consistent across all injuries except concussions and spasms (Figure 2.4), both of which showed a nearly linear increase in frequency as the game progresses. In a separate analysis of concussion and spasms, a significant chi-square was observed for concussions (χ^2 (3) = 30.698, $p<0.001$), but not spasms ($p>0.05$).

Figure 2.3. Number of injuries in Men's Football by quarter and injury type.



Number of injuries by quarter and type in men's football. Sprains were the most common type of injury, but it is important to note the inverted-U shape of injury occurrence for most injuries (sprains most notable in diagonal hatched bars) versus the linear relationship for concussions (checkered bars).

Figure 2.4. Number of concussions and spasms by quarter in Men's Football.

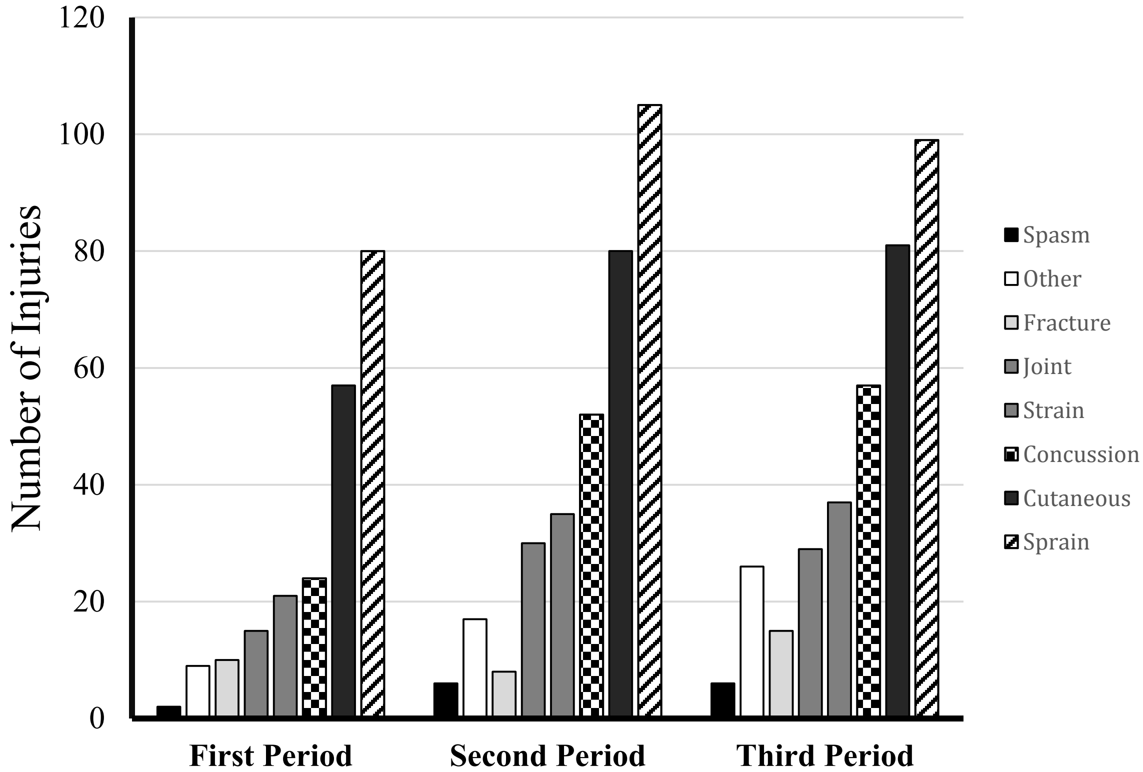


Number of concussions and spasms by quarter in men's football. Both concussions and spasms were observed to increase in the later quarter ($p<0.05$) by chi-square analysis.

2.5.5 Analysis of injuries in Men's and Women's Ice Hockey

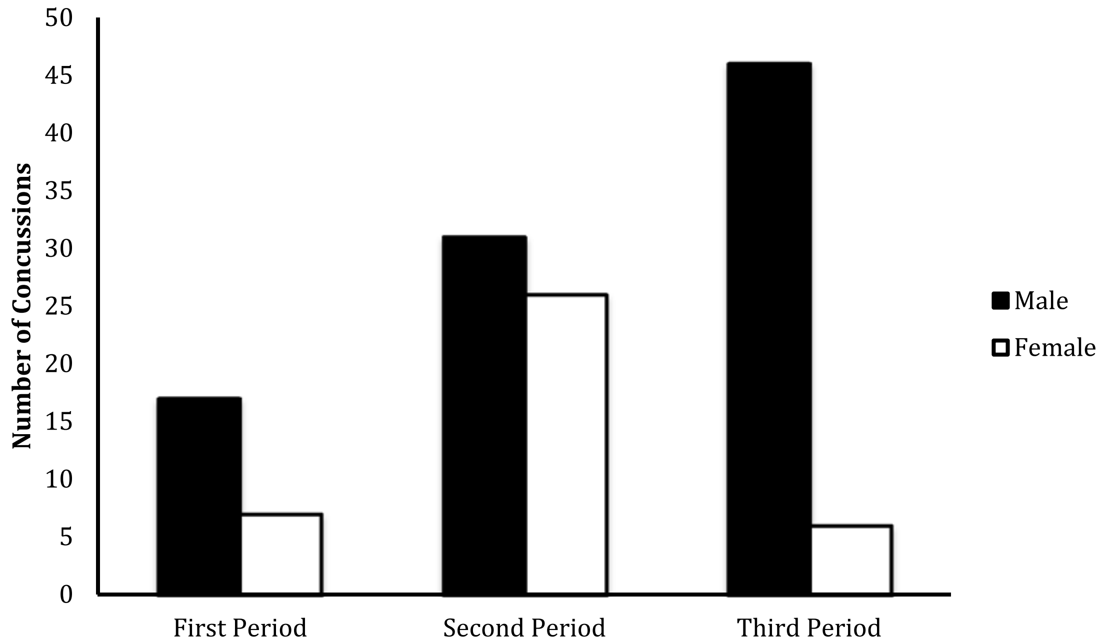
There was a significant increase in injury frequency by period in both men's and women's ice hockey, χ^2 (2) = 15.236, p<0.001. However, while women's ice hockey showed a linear progression with respect to injury occurrence by period, men's hockey actually had slightly more injuries in the second period than in the third. When analyzed together, the injury rate trended upwards from first to second period, then plateaued between the second and third period. There was no significant relationship between injury type and game time as an increase followed by a plateau was consistent for every type of injury in ice hockey, χ^2 (14) = 10.241, p=0.744. However, in a separate analysis of concussions by sex, it was observed that concussions were more frequent in the second period for women whereas they were more frequent in the third period for men, χ^2 (2) = 15.236, p<0.001 (Figure 2.6).

Figure 2.5. Number of injuries in Men's and Women's ice hockey (combined) by period and injury type.



Number of injuries by quarter and type in men's and women's ice hockey. Sprains were the most common type of injury, but it is important to note the increase and plateau injury occurrence for most injuries (sprains most notable in diagonal hatched bars) versus the linear relationship for concussions (checkered bars).

Figure 2.6. Number of concussions in Men’s and Women’s Ice Hockey by period.



Number of concussions for male and female ice hockey players by period

2.5.6 Analysis of Injuries by Season Segment

The injuries included in the previous analyses were from full-season competition data only. Each season could be further broken down into preseason, regular season and post season. Injury rate was calculated for each season segment according to the amount of exposures during each segment (Table 2.5). Athletes were less likely to be injured in the post-season as there were only 10.7 injuries per every 1000 athletic exposures versus 17.9 and 19.1 for regular season and preseason play, respectively.

Table 2.6. Injuries across season segment by exposure type.

	# of Athletic Exposures	**# of Injuries**	**Injuries per 1000 exposures**
Regular Season Competition	825,317	14,767	17.9
Regular Season Practice	2,831,496	8,787	3.1
Post Season Competition	51,496	552	10.7
Post Season Practice	231,980	511	2.2
Preseason Competition	23,282	444	19.1
Preseason Practice	1,532,863	12,973	8.5
Total	5,496,434	38,034	6.9

Number of exposures, injuries and subsequent injury rate with respect to competition and practice in different season segments. See text (2.4.3) for definition of athletic exposures.

2.6 Discussion

As hypothesized, injury rate was higher in the second half of competition than in the first half. This trend was evident across all sports analyzed. Rate of increase in injury between halves was nearly uniform across all other sports. Since men's football was excluded, women's field hockey was also removed in the analysis of sex in order to ensure an equal comparison. Without football, the injury rate by half is actually 2816 (40.4%) in the first half, to 4161 (59.6%) in the second half. These results are not surprising, given the similar findings of previous one-sport studies. Recall that individual sports such as rugby (17, 18, 24) and badminton (12) have all been shown to have a higher rate of injury later in competition. The authors who discover this phenomenon have suggested that it is due to the effects of fatigue on the mechanical function of athletic movements. Findings of the current study support these suggestions with similar injury data, and also augment them by refuting other possible explanations for the relationship between injury rate and exposure time.

Specifically, due to the multi-sport nature of this study, it was possible to eliminate environmental change as a factor that could result in a higher rate of injury in the second half. Theoretically, rain or snow could start towards the later stages of an outdoor event, resulting in compromised ground conditions and a subsequently increased frequency of injuries. However, an analysis of injury rate by half across all sports determined that there is no difference in relative injury rate between sports. Since no change in environment occurs in indoor sports, the rate change observed in the second half must be attributed to internal factors. From this, it is important to note that indoor sports like basketball and outdoor sports like soccer both showed very similar increases in relative injury rate in the second half.

Given this parallel, it would be reasonable to assume that environmental change is not a factor in outdoor sports, with respect to injuries per half.

Of the potential internal factors, motivation to win could translate to a more competitive second half, as this is the point where the game is 'on the line'. Being that the outcome of the game is determined in the second half, athletes may save their best effort for this time, where they will begin to play faster or more aggressively. As suggested by Gabbett (19), an increase in match intensity could lead to more injuries. On the contrary, the present study shows, however, that an elevation in competitiveness of a game situation does not necessarily lead to more injuries. This study found that injury rate in the post-season is significantly lower (10.7 injuries per 1000 athletic exposures) than injury rate in the preseason (19.1/1000) and regular season (17.9/1000). Given this finding, the suggestion that the increase in injuries is due to increased competitiveness seems dubious; players are actually *less* likely to leave during intense competition. Another internal factor seems to be the more likely answer, however, it could be the case that less injury-prone teams are the ones that make the postseason. Further research is needed in this regard.

As noted previously, the authors of the aforementioned studies of sports injuries suggested fatigue as an underlying cause (12, 17, 18). These competition-based claims would also be supported by laboratory-based research. Specifically, fatigue has been shown to cause improper movement patterns during motor tasks. For example, alterations in running gait (44) or extraneous movements during jump landings (5, 45, 48) have been observed following a fatiguing protocol. Alterations in proper biomechanical function could lead to injury of the joints involved in the task. Given the support for fatigue as a contributor, and since there is no strong case for other causes; fatigue becomes the most logical contributor to increased injury rate in the second half. To examine this relationship, analysis of each type of injury is required. As some injuries have obvious connections between rate and fatigue, those injuries should increase more in the second half than injuries with little relation to fatigue.

This distinction is not so clear with respect to skeletal fractures. Since the skeleton is a structural organ rather than a massive energy-user like skeletal muscle, one could expect that bone is not susceptible to exercise-induced fatigue. While this may be true from an energy consumption standpoint, fatigue loading has been shown to result in micro trauma, as well as increased stiffness of bone (31). This compromised functional integrity of the bone tissue could, in theory, result in a decrease in the load required to elicit fracture (31). Additionally, since we know that muscle is in place to maintain the structure of the body, as muscle (or the nervous system) fatigues, the body could become less able to optimize movements or resist potentially dangerous situations (5). Upon investigation, however, neither of these theories is supported. Though there is a slight increase in fracture rate in the second half, it does not reach significance.

While functional differences in the muscular system during exercise do not appear to alter the rate of bone injury in athletes, there does appear to be a direct effect on muscular injuries. The data shows that 57.3% of all muscular strains occurred in the second half. The current understanding of the dynamics of muscle fatigue makes this phenomenon predictable; as muscle fatigues, it loses function and without appropriate precaution, may become susceptible to failure (33). This may be why there are a greater number of hamstring injuries relative to quadriceps injuries late in soccer matches (7). The hamstrings fatigue faster than the quadriceps during running due to a higher percentage of anaerobic type II fibers (21), as well as the necessity of eccentric contraction of the hamstrings at the end of the swing phase

(34, 51). While the increase in muscular injuries late in games is predictable, other trends are not so obvious.

One injury type that increased in the second half without a clear, direct cause was ligament sprain, as 54.7% of all sprains occurred in the second half of competition. This is the lowest percentage of all injuries that showed rate changes in relation to duration of play. Muscular fatigue or imbalances appear to be a risk factor for sprains (22), which would indicate that other factors are in play before local fatigue would actually affect the structure of the ligament. In fact, ligaments become less resistant as exercise continues and temperature increases, meaning they are actually able to sustain more load in these situations (42). As such, two potential explanations for this relationship between exposure time and sprains exist. The first is that fatigued muscles do not support the structural tissues like bone and ligaments as well as they did before fatigue set in. Though some injuries would occur no matter what, perhaps less fatigued muscles could reduce the overload on the ligament. The second explanation for higher sprain rates in the second half is that the cognitive effects of fatigue or dehydration delay reaction time, and drain spatial awareness and proprioception (3, 6, 53). This may result in an athlete being hit off guard, or not being able to react appropriately to a potentially dangerous situation, in turn, resulting in a sprained ligament. Other joint injuries like subluxations and separations occurred with nearly the exact same relative frequency between halves as sprains did.

Cutaneous injuries like lacerations, contusions or abrasions would predictably be very evenly dispersed throughout the game. However, this is not the case, as these injuries were strongly correlated with the second half. This could be due to numerous impacts throughout a game culminating in a contusion that does not allow the athlete to continue. It could also be the case that cutaneous injuries are more frequent in the second half simply because they occur simultaneously with other injuries, as 56.2% of all cutaneous injuries occurred in the same game as another injury. The fact that the players are not identified makes this explanation impossible to prove.

Spasms and cramps, predictably, were most associated with the second half. This is intuitive, because they are thought to be associated with muscular fatigue (40), which occurs during or following prolonged exertion and is linked with dehydration. Though there are criticisms of the dehydration theory of muscle cramps, they do occur most often in circumstances that would likely result in dehydration, such as prolonged exercise or exposure to hot environments (40). Given this propensity for spasms and cramps to occur during states of dehydration, the fact that their injury patterns are so closely mirrored by those of concussions is very interesting.

First, these two injuries are the most closely associated with the second half, as 68.5% of all spasms and 64.1% of all concussions occurred in the second half. Cutaneous injuries were next at a 62.4% occurrence in the second half, followed by strains at 60.9%. When viewing this comparison alone, there is no obvious connection, however, there are other instances where the parallels between spasms and concussions are present and more unique.

This is where within-sport analyses become important; specifically with regards to football and ice hockey. In football, injuries followed an inverse-U shaped pattern of frequency. Injuries of each type were low in the first quarter, high in the second and third quarter, and lowered to an intermediate level in the fourth quarter, except two. Both concussion and spasm followed a linear progression. While spasms did not reach significance due to the low occurrence, rates for both injuries were low in the first quarter, high in the fourth quarter and an intermediate level in the second and third quarters. Again, the increase in spasms as gameplay progresses is intuitive, however there is currently no explanation for why concussions continuously increase while other injuries do not. Furthermore, though there is a continuous increase in these two injuries in football, this is not the case in ice hockey. In ice hockey, all injuries increase from the first period to the second, and then plateau from the second to the third. While this could be construed as a flaw in the argument for dehydration as a predictor for concussion occurrence, the following must be considered: ice hockey is played in short shifts with unlimited interchange. Hockey players are afforded ample time to rehydrate because they typically only play about a third of the game. Perhaps the effects of dehydration are hidden in this sport due to the relatively frequent opportunity to rehydrate.

The final analogous trait of concussion and spasm is the relative difference in rate change between men and women. Spasms occur in the second half at 63% and 74.1% for men and women, respectively, and though due to the small sample size this is not significant, it is approaching significance where others injuries are not. When football and field hockey are included in the analysis in order to increase the sample size, this relationship is very nearly significant (data not shown). Similar differences are present and significant for concussions, as these figures are 57.7% and 69.6% for men and women respectively. Joint injuries showed the next biggest difference in relative rate change at 55.3% for men and 59.2% for women. The consistent parallels between concussion and spasms and cramps offer the relationship between concussion and dehydration enough merit for further investigation, particularly when previous findings are considered.

Recall that dehydration of a 2-3% loss in body weight has been shown to result in a decrease of approximately 10% of cerebrospinal fluid (9). Depletion of the brain's natural cushioning could cause otherwise sub-concussive impacts to result in concussion. Furthermore, the alterations in intracranial fluid balance observed in post-concussive athletes (32) could be why they are more susceptible to additional concussions (49). While obviously some blows will result in a concussion no matter the fluid concentration in the brain, perhaps a decrease in CSF cushioning could skew the rate towards more frequent injuries while dehydrated. This effect may be more pronounced in women in the luteal phase, as high progesterone concentrations have been associated with lowered CSF volumes (23), which may result in sex differences in concussion. The data would suggest that this is a worthwhile possibility to explore, as no other explanation is perfect.

For one, the connection between concussion rate and exposure cannot solely be attributed to cognitive deficits associated with fatigue because there are differences in relative rate change for each injury. While cognitive changes may have some role, if they were the only factor, rate change would theoretically be uniform across all injury types. Furthermore, this proposal cannot account for sex differences in concussion diagnosis because women are actually less likely to exhibit concussion-like symptoms following acute exercise than prior to exercise, whereas men are more likely to be symptomatic (20). This indicates that women are not diagnosed at a higher rate later in the game simply because the exercise has made them more symptomatic.

There is also no evidence to suggest that women are more susceptible to cumulative impact concussions than men. This possibility would be further refuted by the fact that women sustain fewer impacts throughout competition than men do. This is simply due to the rule differences between female and male sports. It could be that the relatively lesser muscle mass in females' necks becomes fatigued and therefore they are less able than men to stop or prevent cranial accelerations that could result in a concussion, however, this explanation does not account for the other parallels between spasms and concussion.

2.7 Limitations

While Datalys provided useful information regarding the type of injury and the mechanism of injury, this data is not sufficient to prove that an injury was caused by fatigue or dehydration. Similarly, there is no way to prove that any of the injured athletes were fatigued or dehydrated at all. Since playing time is not distributed evenly among players, a state of fatigue simply had to be assumed later in the game. This is problematic because a soccer player may have been injured directly after substitution in the late stages of a game, so the actual amount of exposure to gameplay prior to injury is not high enough for fatigue to be a major factor. Since, however, the playing time of each athlete is not recorded, this method was the only means available. To maintain confidentiality, Datalys withholds information specific to the game and athlete such as date and location of home field or return to play date. This environmental information could be valuable for future studies examining a relationship between injury rate and dehydration, since dehydration is theoretically more likely in the heat. The return to play data provided in this study was not detailed enough to measure severity of injury. As a result, the case may be that even though more injuries occur in the second half, more severe injuries happen in the first half, and therefore the effect of exposure on time missed is nil.

Furthermore, the actual recording time of injuries may not have been entirely accurate. A player may have left a game following aggravation of an injury, however, the injury may have actually occurred earlier in the game. This potential confound may have skewed the results in favour of injuries happening later in the game, even though this is not the case. The benefit of having such a large dataset is that the number of injuries reported would limit this type of occurrence. Lastly, due to the relatively infrequent occurrence of some injuries, data may indicate some trends that do not actually exist.

2.8 Significance

This study is the first of its kind in multiple respects. To start, it is the first study of injury trends with respect to exposure time that can provide a standardized 'between sport' analysis. This allowed the unique opportunity to account for potential differences in injury rate within sport. For instance, a change in game strategy at halftime in soccer may lead to more 'headers' in the second half, which could potentially lead to more concussions. The fact that concussion rate increases in the second half in *all* sports makes this refutation of fatigue as a cause of injury less plausible. The inclusion of multiple sports over a five year span also resulted in a very large sample size; the largest of any study of its kind.

This study is also the only to provide information on both male and female athletes. Inclusion of both sexes provides a unique perspective into potential causes of injury, as well as possible injury prevention methods for each sex.

These unique aspects also allow further insight into what is perhaps the most interesting part of this study's findings, which is the difference in rate of change for each injury. For example, change in rate of fracture between halves was shown to be consistent between sexes and across sports, whereas rate change for concussions was much greater in women. The depth of information available allows for more intricate analysis, and consequently, more answers.

2.9 Future Directions

Results obtained from this study could lead to changes in game management in order to keep players safe and ultimately protect the interests of a given sport. Many aspects of professional and amateur sport have been changed to specifically limit injury. For example, if only one type of injury is examined, concussion, seemingly every major sports organization in North America has taken action to prevent concussions and other head injuries. The NFL reviewed its ban on helmet-to-helmet collisions with a view to implementing stricter penalties including suspension from the game and heavy fines(28). In addition, the NFL enforces rules to protect the quarterback during play and has paired with General Electric in the development of a 60 million dollar endeavor to fund concussion prevention, diagnosis and treatment research (55). Major League Baseball (MLB) has mandated that all base coaches wear protective helmets, and is experimenting with the idea of having pitchers wear helmets as well (52, 54). In fact, after this "non-contact sport" dealt with extended absences of great players due to concussion, a new seven-day disabled list was introduced that allowed MLB players with suspected concussions time to recover, without missing play for too long (27). To date, most of the research and resultant policies have been based on the development of better equipment or changes to rules of play. However, changes in rules of play and equipment have not had the expected decline in incidence of concussions. In fact, the rate of concussions continues to rise (10). Consequently, novel approaches that take into consideration the physiology of athletes may be suitable to augment the head injury, as well as other injury, prevention strategies already implemented in organized sport.

Additionally, the findings of this research should lead to new studies, which could account for the effects of dehydration on injury risk. Aspects of dehydration could be added to the studies that were used to analyze the effects of fatigue on motor performance. This would allow some measure of the effects of dehydration on motor function. Differences between the dehydrated groups and hydrated groups could shed light on the effects of hydration status on injury susceptibility.

To sum, this study supported the hypotheses that injuries would occur more frequently later in games, and that this effect would be greater in women. The hypothesis that this increase in injury rate later in games would be due to muscular, joint and head injuries was also supported. Sex differences in patterns of concussion frequency are worth exploring in further detail.

2.10 Conclusion

In conclusion, injuries are more common later in competition in all sports. Fractures were the only injury to not show a significant increase, while muscle fatigue-related (i.e. spasms/cramps) and concussions were the most associated with the second half of competition. Women showed a disproportionately large increase in concussions in the second half relative to men and approached significantly greater increases with respect to spasms and cramps. These trends may be related to fatigue and/or dehydration.

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APPENDICES

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Today's Date: May 28, 2014
Principal Investigator: Mr. Craig Harwood
REB Number: 31675
Research Project Title: REB# 14-116: Effect of season and game/practice time on injury rate in men's and women's NCAA sport
Clearance Date: May 28, 2014
Project End Date: March 31, 2015
Milestones:
Renewal Due-2015 03 31(Pending)

This is to inform you that the University of Windsor Research Ethics Board (REB), which is organized and operated according to the Tri-Council Policy Statement and the University of Windsor Guidelines for Research Involving Human Subjects, has granted approval to your research project on the date noted above. This approval is valid only until the Project End Date.

A Progress Report or Final Report is due by the date noted above. The REB may ask for monitoring information at some time during the project's approval period.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the REB. Minor change(s) in ongoing studies will be considered when submitted on the Request to Revise form.

Investigators must also report promptly to the REB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

Forms for submissions, notifications, or changes are available on the REB website: www.uwindsor.ca/reb. If your data is going to be used for another project, it is necessary to submit another application to the REB.

[redacted]esearch.

Pierre Boulos, Ph.D.
Chair, Research Ethics Board
Lambton Tower, Room 1102 A
University of Windsor
519-253-3000 ext. 3948
Email: ethics@uwindsor.ca

c.c. Dr. Kevin Milne, Supervisor, Kinesiology

Appendix B

DATALYSCENTER®

NCAA® Injury Surveillance Program

DISC

Datalys Injury
Statistics Clearinghouse

Data Request Instructions

Users Guide and Information Packet
Application Packet

Authored by: Datalys Center for Sports Injury Research and Prevention, Inc
Creation Date: August 2010
Last Revised: June 2012
Version: 1.1

INTRODUCTION:

Thank you for your interest in the NCAA injury surveillance data. In this packet you will find the instructions, sports, years and variables available as well as the application packet.

Data requests are limited to legitimate scientific inquiries and are reviewed by an external panel of scientists for redundancy (to determine if the same data has already been provided to another researcher), scientific merit (i.e. sound research question), and potential to contribute to the body of knowledge. Requests for marketing data or general descriptive information in lieu of a legitimate research question will not be considered. Panel recommendations are forwarded to the NCAA for final approval.

The current dataset represents the 5-year period spanning the 2004 to 2009 academic years. Several sports have less than 5-years of available data due to the academic year the system began tracking those sports.

DATA REQUEST INSTRUCTIONS

Researchers may apply for subsets of de-identified aggregate data. Generally, these data are considered exempt from Human Subjects Protections; however, researchers are required to provide proof of exemption from their Institutional Review Board (IRB).

Completion of the application is the first step in the process of review by the Datalys Center Independent Review Committee (IRC) and the NCAA. This process is anticipated to take 60 to 90 days depending when a request is submitted relative to the next scheduled IRC meeting. The IRC generally meets once a month to review proposals. Expedited requests for review are not possible and incomplete proposals will delay the process. If the IRC approves an application, it is then forwarded to the NCAA for final approval. The NCAA retains the right to deny any request without explanation.

When a request is granted, the Primary Investigator will be required to sign a *Data Use Agreement*. Codebooks, methods, and datasets are provided once all approvals and paperwork have been received.

Every sport will have a codebook for Exposures and Injuries included in that sport's data set. However, below is a general listing of the types of variables that are found in each of the exposure and injury codebooks.

The initial set of data files available are for NCAA Injury Surveillance System data for the period 2004/05 to 2008/09. Data will be available for all the sports listed in the table below. Note that some sports do not have data available for the entire five year period.

Athletic Injuries

The injuries and illnesses entered by certified athletic trainers included in these data sets are only those classified as athletic injuries. Athletic trainers could enter injuries and illnesses that occurred outside of athletic competition, but these injuries were not included in the 2004-2009 dataset. The data include all health conditions that the certified athletic trainers determined to be athletic injuries. In a small number of cases, these include infections and other conditions that some data users may consider to be non-injury.

Time Loss Injuries

Only injuries that resulted in one or more days of lost participation are included in the 2004-2009 dataset, i.e., zero-days, time loss injuries are not included in the data sets.

Sampling Weights

Post-stratification sample weights are included on the data files. These weights allow the researcher to make estimates about the overall population of NCAA athletic injuries. The weights are computed at the school-sport-year level. Researchers need to consider the limitations associated with making national estimates using data collected from volunteer systems.

Data Request Process

You will need to complete the Data Request Form and return it to the Datalys Center (contact information is below). Your completed application will be evaluated by the Independent Review Committee (IRC) and the NCAA. Again, this process is anticipated to take 60 to 90 days depending when a request is submitted relative to the next monthly scheduled IRC meeting. If your application is approved by the NCAA, the Datalys Center will provide the investigator with the *Data Use License Agreement* for completion as the final step in the process before data sets are released.

Data Use License Agreement

If your application for data release is approved, you will be provided with the *Data Use License Agreement*. The *Data Use License Agreement* needs to be read, signed and returned to the Datalys Center along with any applicable fees prior to data being released. Please note that the *Data Use License Agreement* includes a provision requiring proof of IRB approval.

Fee Schedule

These data sets are provided for free through the generous financial support of the NCAA and would not be possible without the time and extraordinary effort of athletic trainers who are dedicated to the prevention and treatment of sports injuries.

Form Instructions

- Date of Application: Date submitted to the Datalys Center.
- Institution: List the institution name of the PI.
- NCAA-ISP Participant: Check the appropriate button (will be verified).
- Primary Investigator (PI): List only the name of the lead investigator.
- Credentials: Provide the lead investigators credentials (MD, PhD, etc).
- Title: Lead Investigator's Title (assistant professor, etc).
- Department: Lead investigator's department (orthopedics, etc).
- Street Address: Mailing street address of PI.
- City, State and Zip code: City, state and zip of PI.
- Email: Work email of PI (do not provide gmail or other non-work related email).
- Office Phone: PI's office phone.
- Purpose of Your Request: Check button (limited to peer-reviewed manuscripts and dissertations).
- Student Status: Check the appropriate box indicating your academic status
  If this is a student project, you must provide the following:
  a. Mentor's Name: Provide full name of mentor
  b. Mentor's Institution: Provide full institution name
  c. Mentor's Title: Mentor's title (assistant professor, etc)
  d. Mentor's Email: Provide the mentor's work email
  e. Mentor's Phone Number: Provide the mentor's office phone number
- Human Subjects' Protections Approval: Check appropriate button
- Project Funding: Check the appropriate box indicating if project is funded, if yes, by whom.
- Collaborators: Provide the name, title, institution and role of each investigator
- Project Title: Identify the preliminary title of the proposed manuscript or dissertation.
- Project Synopsis: Briefly describe your proposed project, purpose, approach, expected outcomes.
- Specific Aims: Provide a list of specific aims (note over-reaching or broad aims should be avoided).
- Significance & Expected Outcomes: Describe how project will contribute to the body of knowledge.
- Statistical Analyses: Describe the statistical analyses you plan to perform
- Sports, Years & Variables: Identify the sports, years and variables requested from the lists provided.
- Signature:

Contact Information

Please return all completed applications in PDF format to the Datalys Center at disc@datalyscenter.org

AVAILABLE SPORTS AND YEARS

<u>Sports Available for 5 Years</u>

Men's Football	2004/05 – 2008/09
Women's Field Hockey	2004/05 – 2008/09
Men's Soccer	2004/05 – 2008/09
Women's Soccer	2004/05 – 2008/09
Women's Volleyball	2004/05 – 2008/09
Men's Basketball	2004/05 – 2008/09
Women's Basketball	2004/05 – 2008/09
Men's Wrestling	2004/05 – 2008/09
Women's Gymnastics	2004/05 – 2008/09
Men's Ice Hockey	2004/05 – 2008/09
Women's Ice Hockey	2004/05 – 2008/09
Men's Lacrosse	2004/05 – 2008/09
Women's Lacrosse	2004/05 – 2008/09
Men's Baseball	2004/05 – 2008/09
Women's Softball	2004/05 – 2008/09

<u>Sports Available for 4 Years</u>

Men's Cross Country	2005/06 – 2008/09
Women's Cross Country	2005/06 – 2008/09
Men's Indoor Track	2005/06 – 2008/09
Women's Indoor Track	2005/06 – 2008/09
Men's Outdoor Track	2005/06 – 2008/09
Women's Outdoor Track	2005/06 – 2008/09
Men's Tennis	2005/06 – 2008/09
Women's Tennis	2005/06 – 2008/09

<u>Sports Available for 3 Years</u>

Men's Swimming and Diving	2006/07 – 2008/09
Women's Swimming and Diving	2006/07 – 2008/09

VARIABLES FOR REQUEST FROM EXPOSURE AND INJURY CODEBOOKS

Exposure Variables

Variable Name	Variable Label
ACADEMIC_YR	Academic Year (20xx-xx)
SPORTCODE	Sport Code
EXP_KEY	Exposure Unique Identifier
DIVISION	Primary Division
DIVISION_FB	Football Division (ONLY FOR FOOTBALL REQUESTS)
SEASONCODE	Season Segment
EVENT_TYPE	Event Type
HOME_GAME	Competition Type
PRACTICE_TYPE	Practice Type
ATHLETE_COUNT	Participation Count
SURFACE_TYPE	Surface
EQUIPMENT_FB	Football Equipment (ONLY FOR FOOTBALL REQUESTS)
WT_FIN	Sampling Weight (post-stratified by Division and Year)

Injury Variables

Variable Name	Variable Label
ACADEMIC_YR	Academic Year (20xx-xx)
EXP_KEY	Exposure Key (links to exposure file)
INJ_DX_KEY	Injury Key
MULTIPLE_INJURIES	Multiple injuries to Same Body Part Key
PRIMARYDIV	Sport Division
SPORTCODE	Sport Code
DIVISION_FB	Football Division (ONLY FOR FOOTBALL REQUESTS)
SEASON	Season Segment
EVENT_TYPE	Event Type
GAME_TYPE	Competition Type
PRAC_TYPE	Practice Type
INJ_EVENT_TYPE	Injury Event Type
PRACTICE_SEGMENT	Practice Segment
ACTIVITY	Player Activity at Time of Injury
GAME_POSITION	Athlete's Position at Time of Competition Injury
GAME_TIME	Game Time
GAME_FIELD_LOC	Location on Field or Court at Time of Competition Injury
INJ_MECH_BASIC	Basic Injury Mechanism
INJ_MECH_SPEC	Specific Injury Mechanism
TIMELOSS	Days Lost from Participation
OUTCOME	Outcome
BODYPART_SYSTEM	Body Part or System Affected
SPEC_INJURY_CODE	Specific Injury
TYPE_INJ	Type of Injury
SIDE	Side of Body
RECUR	Injury Recurrence
CHRONIC	Chronic Injury
SURGERY	Surgery Resulted from this Injury
WT_FIN	Sampling Weight (post-stratified by Division and Year)

DATA REQUEST APPLICATION FORM

Please complete this form in its entirety. Incomplete forms will not be processed. This application should only be completed by scientific investigators requesting access to de-identified, line item exposure and injury data from the NCAA's Injury Surveillance Programs. Requests must have a legitimate scientific research question. Because this is a free service provided to scientific investigators, data requests for marketing, media or for general information in lieu of a scientific question leading to a peer-reviewed manuscript will not be considered.

Access to the data is a 2-step process. Approval by Datalys Center Independent Review Committee (IRC) does not guarantee requests will be approved by the NCAA. Requests may take several months to process depending on volume and when the application was received. Applications submitted by investigators from NCAA Injury Surveillance Program participating institutions will receive priority processing, but must meet the same criteria for approval.

Primary Investigator (PI) Information

1. **Date of Application:** June 6, 2014

2. **Institution:** University of Windsor

3. **NCAA-ISP Participant:** YES ☐ NO ☑

4. **Primary Investigator:** Craig Harwood

5. **Credentials:**

6. **Primary Investigator's Title:** Graduate Student

7. **Department:** Kinesiology

8. **Street Address:** 401 Sunset Ave

9. **City, State, Zip:** Windsor, Ontario, Canada, N9B 3P4

10. **Email:** harwoodj@uwindsor.ca

11. **Office Phone:** (519) 903-3244

Proposal Information

12. Purpose of Request: PEER-REVIEWED MANUSCRIPT ☐ DISSERTATION ☑ OTHER ☐

If OTHER, describe:

13. Student Status: DOCTORAL STUDENT ☐ MEDICAL STUDENT ☐ MASTERS STUDENT ☑ NA ☐

If this is a student project, you must provide the following:

a. **Mentor's Name:** Kevin Milne

b. **Mentor's Institution:** University of Windsor

c. **Mentor's Title:** PhD

d. **Mentor's Email:** kjmilne@uwindsor.ca

e. **Mentor's Phone Number:** (519) 253-3000 (2542)

14. Human Subjects' Protections Approval: APPROVED ☑ IN REVIEW ☐ NA ☐

Data will not be released without proof of human subjects' protections approval or exemption from the PI's Institutional Review Board. If approved or in review, attach letter from IRB in PDF format along with this application. Applications in IRB review will be considered but data will not be released until proof of approval or exemption is provided.

15. Project Funding: YES ☐ NO ☑

If funded, identify the funding agency:

16: Collaborators (Name, Title, Institution, and Role on Project):

17. Project Title:

Effect of season and game/practice time on injury rate in men's and women's NCAA sport

18. Project Synopsis *(limited to 3500 characters):*

Every major sports organization in North America has taken action to prevent injury. For example, hockey, football, and baseball players wear protective gear/uniforms specific to their sport, competition is typically sectioned (periods, quarters, halves, etc.) to allow athlete recovery and rule changes such as the NFL implementing stricter penalties, including suspension from the game and heavy fines for helmet to helmet hits or enforcing rules to protect the quarterback during play are specific to the attenuation of injury. Moreover, athletic injury prevention research can be a lucrative industry. For example, the NFL recently paired with General Electric in the development of a 60 million dollar endeavor to fund concussion prevention, diagnosis and treatment research. Nonetheless, the etiology of athletic injury is still not entirely clear. Novel approaches that take into consideration the physiology of athletes may help to improve athlete protection and preparation.

To that end, fatigue has been found to cause some types of injury. Muscle cramping is a notable example that occurs more frequently in fatigued athletes, even though the causal factors are under debate. However, there is limited data showing a relationship between fatigue and other injuries. For example, females show a disproportionate percentage of injuries occurring in the second versus first period (51.72% versus 33.98% respectively), possibly because there is no rink flooding between the first and second periods, and consequently, no rest time. Additionally, in the NHL ‘01- ‘02 season, players averaging over the league-wide median in ice-time per game were almost twice as likely to sustain a concussion (16 concussions below median versus 29 concussions above median). A fatigued athlete may be more prone to placing his or herself in a vulnerable position where impact is likely to occur or may have other physiological changes (e.g. dehydration, altered neuromuscular control, etc.) that affect normal physical performance.

To date, the impact of fatigue on the susceptibility to injury is limited to a few sports (running and football, in particular) in separate analyses and a comparison of what type of injury is more likely to occur at different parts of competition is unknown. This is likely because of the challenges of measuring fatigue during game/practice time and injury frequency. Nonetheless, if the relationship exists, we would expect to observe a greater frequency of injury in environments with more severe weather, where physiological resources are strained or in the latter parts of competition where fatigue is more likely. As such, we would like to determine whether a game time link with injury occurrence is observed in all injuries in a multitude of sports. Moreover, aim to determine whether any sex (gender) differences in injury occurrence with fatigue occur. Using the NCAA Injury surveillance data, we propose to examine these relationships in several sports across both sexes.

19. Specific Aims *(limited to 3500 characters):*

To examine sex, sport and injury type in injury occurrence in relationship to time of playing.

Using the NCAA injury surveillance data, we aim to test the hypotheses that:

" Although injury type and frequency will differ between sports, game and practice injuries will occur more frequently later in competitions/practices

" The relationship between time of playing and injury will be more pronounced for muscle related injuries than impact related injuries.

" Injuries occurring in later playing times will be correlated with greater time loss for that specific injury

" Although females will experience some injuries more frequently than men , the relationship between time of playing and injury will be equal between men and women

20. Significance and Expected Outcomes *(limited to 3500 characters):*

Epidemiological evidence of injury occurrence has only become available because of massive databases such as the NCAA injury surveillance system. The nature of injury is an important consideration in athletic participation and administration. Still, the data regarding injury occurrence is typically specific to particular sports and inclusive of only 1 sex (gender) preventing direct comparison of males and females. Nonetheless, this type of information provides the basis for strategies to mitigate injuries. By including a comparison of injury type, sport personnel (e.g. coaches, therapists, trainers, etc.) could modify instruction, conditioning or player management systems to ensure certain injuries are reduced. Moreover, athletes and their handlers (parents, mentors, etc.) would be made more aware of the specific types of conditioning necessary for optimum performance and health in the sport they want to play. Finally, observation of increased injury rates during later parts of competition may lead to further academic research into mechanisms, diagnoses and prevention of clinically relevant (i.e. on the playing field) fatigue related injuries.

21. Statistical Analyses *(limited to 3500 characters):*

We will employ proportion/rate methods in our main statistical analyses. Our primary variables will include SPORT (basketball, football, field hockey, soccer, lacrosse), SEX (male, female), INJURY TYPE (grouped by region: head, upper, lower AND type: musculotendonous, ligament, skeletal, superficial, etc), GAME TIME/PRACTICE/GAME SEGMENT (Binned into early, mid, late by time of injury), SEASONTIME (binned into early, mid or late season) and TIME LOSS (binned by days or weeks). We will also control for position, recurring or chronic injuries and how the injury occurred (e.g. impact versus running).

All statistical analysis will occur using IBM PASW version 20 or above. A Chi square test of independence will occur on categorical (e.g. sex) and nominal binned data. Corrections for continuity will be applied and bins collapsed when necessary and possible. Actual and expected counts and proportions will be reported in multiple R (row) x C (column) tables and figures along with statistical significance at an alpha of $p<0.05$. Higher order proportion analysis will be used to control for some variables such as chronic or recurring injuries.

22. Sports, Years and Variables *(limited to 3500 characters):*
You may request and entire dataset (e.g. Football for 2004/05 – 2008/09 or a subset Football 2005/06)

Men's Football 2004/05-2008/09
Women's Field Hockey 2004/05-2008/09
Men's Soccer 2004/05-2008/09
Women's Soccer 2004/05-2008/09
Men's Basketball 2004/05-2008/09
Women's Basketball 2004/05-2008/09
Men's Lacrosse 2004/05-2008/09
Women's Lacrosse 2004/05-2008/09
Men's Ice Hockey 2004/05-2008/09
Women's Ice Hockey 2004/05-2008/09

ACADEMIC_YR
SPORTCODE
SEASONCODE
PRIMARYDIV
EVENT_TYPE
GAME_TYPE
PRAC_TYPE
PRACTICE_SEGMENT
ACTIVITY
ATHLETE_COUNT
INJ_EVENT_TYPE
OUTCOME
GAME_POSITION
GAME_TIME
BODYPART_SYSTEM
TYPE_INJ
INJ_MECH_BASIC
SPEC_INJURY_CODE
CHRONIC
RECUR

23. Signature: I, ____, hereby certify to the best of my knowledge that the information provided in this document is accurate, truthful and verify that all collaborators have current human subjects' protections training on this _____ day of _____________, in the year of ________________.

Office of the Research Ethics Board
401 Sunset Avenue
Windsor, Ontario, Canada N9B 3P4
T 519-253-3000 ext. 3948
www.uwindsor.ca/reb

Today's Date: May 28, 2014
Principal Investigator: Mr. Craig Harwood
REB Number: 31675
Research Project Title: REB# 14-116: Effect of season and game/practice time on injury rate in men's and women's NCAA sport
Clearance Date: May 28, 2014
Project End Date: March 31, 2015
Milestones:
Renewal Due-2015/03 31(Pending)

This is to inform you that the University of Windsor Research Ethics Board (REB), which is organized and operated according to the Tri-Council Policy Statement and the University of Windsor Guidelines for Research Involving Human Subjects, has granted approval to your research project on the date noted above. This approval is valid only until the Project End Date.

A Progress Report or Final Report is due by the date noted above. The REB may ask for monitoring information at some time during the project's approval period.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the REB. Minor change(s) in ongoing studies will be considered when submitted on the Request to Revise form.

Investigators must also report promptly to the REB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

Forms for submissions, notifications, or changes are available on the REB website: www.uwindsor.ca/reb. If your data is going to be used for another project, it is necessary to submit another application to the REB.

[redacted]esearch.

Pierre Boulos, Ph.D.
Chair, Research Ethics Board
Lambton Tower, Room 1102 A
University of Windsor
519-253-3000 ext. 3948
Email: ethics@uwindsor.ca

c.c. Dr. Kevin Milne, Supervisor, Kinesiology

Appendix C

Re: NCAA DISC
Kevin Milne to: Ross Hayden 19/08/2014 02:05 PM
Cc: "Craig Harwood (harwoodj@uwindsor.ca)"

Hi Ross,

Thanks for this great news. I hope this success carries forward to the NCAA review. Please find the signed agreement attached. If you require any further information, please do not hesitate to contact me.

Take care,

Kevin

Signed agreement.pdf

Kevin Milne, PhD
Associate Professor, Department of Kinesiology
University of Windsor
Windsor, ON Canada
N9B3P4
(519).253.3000 office.2452 lab.4984
kjmilne@uwindsor.ca

Ross Hayden Dr. Milne and Mr. Craig Hardwood, Your applicat... 18/08/2014 04:06:11 PM

From: Ross Hayden <rhayden@datalyscenter.org>
To: "kjmilne@uwindsor.ca" <kjmilne@uwindsor.ca>, "Craig Harwood (harwoodj@uwindsor.ca)" <harwoodj@uwindsor.ca>
Date: 18/08/2014 04:06 PM
Subject: NCAA DISC

Dr. Milne and Mr. Craig Hardwood,

Your application for the use of NCAA ISS data has been approved. Please find attached to this email an End-User License Agreement. We request that both of you sign and return a scanned copy of the End-User License agreement. We have a copy of your REB exemption, so once we have the End-User License Agreements we can forward your materials to the NCAA for review.

Thanks

Ross Hayden
Statistical Analyst
Datalys Center for Sports Injury Research and Prevention
401 West Michigan Street, Suite 500
Indianapolis, IN 46202
317-275-3666
rhayden@datalyscenter.org

message and destroy any copies. Any dissemination or use of this information by a person other than the intended recipient is unauthorized and may be illegal.

[attachment "2012 09 04 Data Use License Agreement - NCAA.pdf" deleted by Kevin Milne/kjmilne/University of Windsor]

Appendix D

DATE: October 29, 2014

Dear Researcher,

Thank you for your interest in working with data from the National Collegiate Athletic Association Injury Surveillance Program (NCAA-ISP). This letter will serve to give you permission to use the NCAA-ISP data to the conditions as specified in the document. This includes the appropriate attribution given for the NCAA-ISP as noted below.

(1) You are free to use the NCAA-ISP data for the specific purpose/study described in your request. Any other use of the NCAA-ISP data will require a separate request for approval.

(2) In any use of the NCAA-ISP, the researcher needs to provide the correct and complete attribution with references as follows,

"The NCAA Injury Surveillance Program data were provided by the Datalys Center for Sports Injury Research and Prevention. The Injury Surveillance Program was funded by the National College Athletic Association (NCAA). The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the Datalys Center or the NCAA. We thank the many athletic trainers who have volunteered their time and efforts to submit data to the NCAA Injury Surveillance Program. Their efforts are greatly appreciated and have had a tremendously positive effect on the safety of collegiate athletes."

(3) Additional information regarding the history and methodology of the NCAA-ISP can be found in our *Journal of Athletic Training* publication, "*National Collegiate Athletic Association Injury Surveillance System: Review of Methods for 2004–2005 Through 2013–2014 Data Collection*," which can be found here. The citation is:

Kerr ZY, Dompier TP, Snook EM, Marshall SW, Klossner D, Hainline B, & Corlette J. National Collegiate Athletic Association Injury Surveillance System: Methodology during 2004/05-2013/14 academic years. Journal of Athletic Training. 2014;49(4):552-560. doi: 10.4085/1062-6050-49.3.58.

(4) On an annual basis, the researcher will provide a status update on the proposed NCAA-ISP-related research by completing an online survey that the Datalys Center will provide.

(5) When your paper has been accepted for publication, the researcher will notify us at disc@datalyscenter.org and provide a copy of the manuscript.

Good luck with your work and please do not hesitate to contact us with any additional questions.

Sincerely,

[redacted]

Zachary Y. Kerr, PhD, MPH
Director, NCAA Injury Surveillance Program
Datalys Center for Sports Injury Research and Prevention

VITA AUCTORIS

NAME: John Craig Harwood

PLACE OF BIRTH: Kitchener, Ontario

YEAR OF BIRTH: 1989

EDUCATION: Belle River District High School, Belle River, Ontario
2003-2007

University of Windsor, Windsor, Ontario
2007-2012 B.Hk

University of Windsor, Windsor, Ontario
2012-2015 M.Hk